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# HISPASAT LAUNCH AND EARLY OPERATIONS PHASES COMPUTATION AND MONITORING OF GEOSTATIONARY SATELLITE POSITIONING

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## ABSTRACT

Since 1974, CNES, the French National Space Agency, has been involved in the geostationary Launch and Early Operations Phases (LEOP) of moving satellites from a transfer orbit delivered by a launcher to a geostationary point (Symphonie A and B, Télécom 1-A, -B and -C, TDF 1 and 2, TELE-X, INMARSAT-2/F1, F2, F3 and F4, ARABSAT 1-C, Télécom 2-A and -B, HISPASAT 1-A).

During the operations and their preparation, the Flight Dynamics Center (FDC), part of CNES LEOP facilities, is in charge of the space mechanics aspects.

What is noteworthy about the Spanish HISPASAT satellite positioning is that all the operations were performed on the customer's premises, and consequently the FDC was duplicated in Madrid, Spain.

The first part of this paper is the FDC presentation : its role, its hardware configuration, and its space dynamics ground control system called MERCATOR. The second part of this paper details the preparation used by the FDC for the HISPASAT mission : hardware and software installation in Madrid, integration with the other entities and technical and operational qualifications. The third part gives results concerning flight dynamics aspects and operational activities.

**Key words :** geostationary satellite positioning, space mechanics, operations, ground control system, man machine interface.

## 1. THE FLIGHT DYNAMICS CENTER

### 1.1 Entities Involved in the LEOP

Different entities of the CNES participating in operations are described in Fig. 1.

For all the LEOP missions before HISPASAT 1-A, these entities including the SCC were on the CNES premises in Toulouse, France. At the end of the LEOP, the satellite was delivered to the customer's Satellite Control Center.

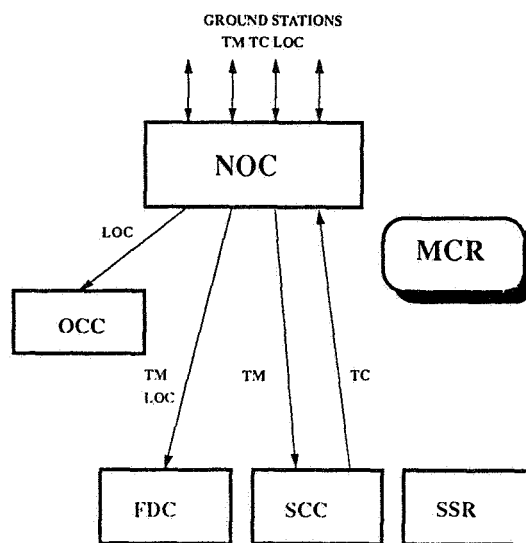


Fig. 1

**NOC :** Network Operations Center (communications with the ground stations all over the world)

**SCC :** Satellite Control Center

**FDC :** Flight Dynamics Center (space mechanics aspects)

**OCC :** Orbit Computation Center (in charge of station designations : providing satellite azimuth and elevation to the ground stations)

**MCR :** Main Control Room (mission management)

**SSR :** Satellite Specialists Room

**TM :** satellite telemetry

**TC :** telecommand

**LOC :** localization measurements

### 1.2 FDC Role and Organization

Among the above entities, the FDC team is responsible for the development of the methods necessary for the resolution of the space mechanics problems during the LEOP.

First, at the beginning of a project, the FDC team issues the flight dynamics mission analysis to prove the feasibility of the positioning in 99,73 % (3 sigma) of the cases of dispersions while fulfilling the satellite and mission constraints and minimizing the propellant mass consumed.

This document gives the results of computation concerning :

- the launch window meaning the authorized time of launch every day of the year,
- apogee maneuvers strategy with a back-up strategy for each maneuver,
- prevision for events (solar eclipses by the earth and moon, sensors blindings, visibilities),
- orbit determination accuracy,
- attitude determination accuracy,
- station-keeping maneuvers strategy.

The second task, before operations, is the development and the validation of the space mechanics software.

During the LEOP, the FDC performs the following tasks :

- orbit determination,
- attitude determination,
- optimization, computation, monitoring and calibration of attitude maneuvers,
- optimization, computation, monitoring and calibration of orbit maneuvers,
- real-time orbit determination with Kalman filter during apogee maneuvers if Doppler measurements are performed,
- operational predictions as geometric and radio-frequency contact, sensors visibilities, solar eclipses by the earth or moon.

Real-time telemetry inputs are received from the satellite while localization measurements are received from the ground stations. Other inputs include technological and mission data given by the satellite manufacturer.

Results of computation include maneuver parameters, graphic monitorings and operational predictions which are transmitted to the other entities involved in the operations through video pages.

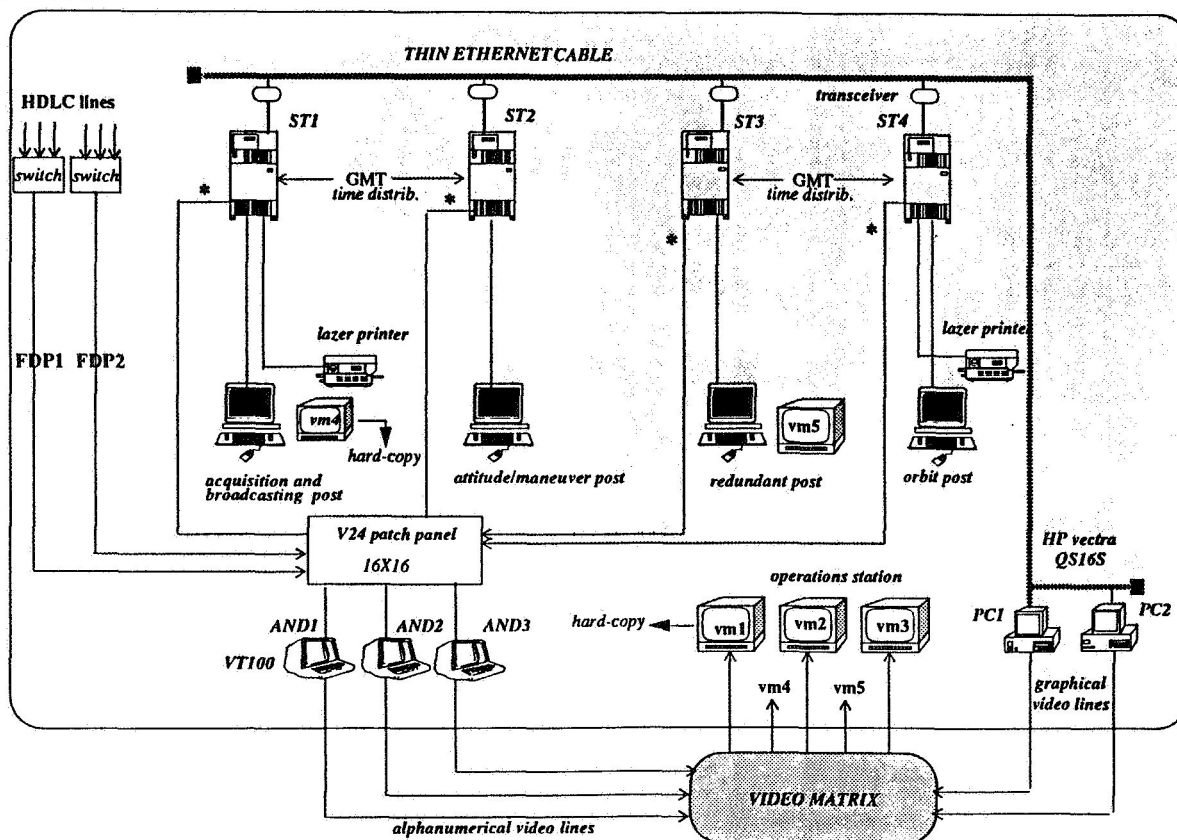
### 1.3 Hardware Configuration

The hardware configuration depicted in Fig. 2 consists of four identical workstations SUN 4/330 (ST1, ST2, ST3 and ST4) linked by a local Ethernet network and two micro-computers (HP Vectra PC1 and PC2) connected to the network in order to handle the graphic video outputs.

Three workstations are sufficient to perform the operations, the fourth one is only for hot redundancy.

Each workstation hosts the same software and is equipped with :

- central memory of 16 Mbytes,
- bulk memory : one 669 Mbytes disk,
- multiplexer : one ALM2 with 16 channels RS232,
- 150 Mbytes streamer unit,
- extension capability : 2 free slots.



vm: video monitor  
AND:alphanumeric display

\* 4 lines: 3 from ALM2 and 1 from serial port A

Fig. 2

Each workstation has the following peripherals :

- alphanumeric console VT220 for generation of video display,
- laser printer,
- Universal Time equipment.

Each micro-computer HP Vectra is equipped with :

- central memory of 1 Mbyte,
- floppy disk unit of 1.2 Mbyte,
- hard disk unit of 40 Mbytes,
- interface board for video, Ethernet coupling.

## 1.4 Software Configuration

### 1.4.1 Operating System

The SUN 4/330 operating system is UNIX which allows multiprocess applications, supports multi-windowing features and offers a wide range of data processing facilities.

1.4.2 Environment Software called MERCATOR (MEthods and Realization for the Control of Attitude and Orbit of satellites)

MERCATOR is mainly composed of two different subsystems :

- real-time acquisition and first treatment of data coming from stations (Ariane telemetry, satellite telemetry, radar measurements and localization measurements). MERCATOR is compatible with HDLC protocol and asynchronous RS 232 transmissions,

- man machine interface : the environment software receives all the flight dynamics software necessary to perform the operational tasks described in 1.2.

MERCATOR allows flight dynamics experts to use within a short response time, various analysis tools in nominal cases as well as in degraded cases :

- real-time or batch mode data processing,
- synchronization of space mechanics modules,
- dynamic displays and plots,
- powerful control of input data and results.

Four people are sufficient to perform a complete positioning of a geostationary satellite and each member of the team can control all the operations even if there is a partial system failure.

Moreover, the workload for software implementation and integration is negligible and MERCATOR can be applied to a wide range of satellites.

The application software organization is depicted in Fig. 3 for geostationary missions. The telemetry and localization data are preprocessed after acquisition and stored in both raw and preprocessed forms. Each application module is autonomous and can be parameterized, operated and monitored through the multi-windowing facilities.

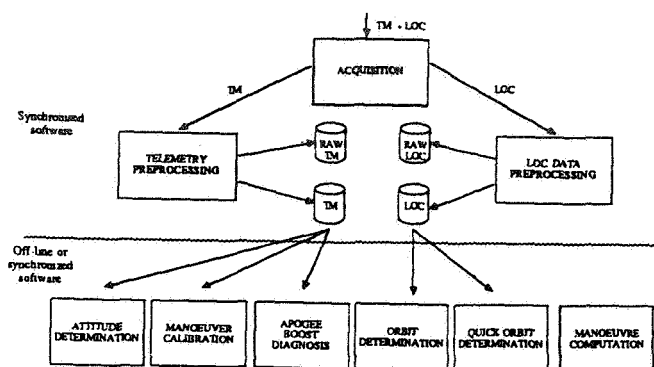


Fig. 3

## 2. THE HISPASAT MISSION

### 2.1 Background of HISPASAT LEOP

HISPASAT S. A., a Spanish company, has selected MATRA MARCONI SPACE (MMS) as prime contractor for the manufacturing and delivery of a space segment including :

- two telecommunication satellites, HISPASAT 1A and 1B delivered in orbit ; the two satellites are located at 30°W,
- a ground control system located in Arganda, near Madrid, including a satellite control center, Ku-band and S-band TTC stations, a payload monitoring center and specific facilities dedicated to LEOP operations.

HISPASAT 1A was launched on September 10, 1992, and HISPASAT 1B's launch is scheduled for April 1993.

The satellite structures are based on a EUROSTAR 2000 platform. They are compatible with a launch on Ariane 4 in upper or lower position.

The main characteristics of the satellites that impact on mission analysis are the following :

. Combined propulsion system :

HISPASAT uses a biquid propulsion system which supplies propellant to both the apogee engine and the attitude and orbit control thrusters. The apogee engine is used to bring the satellite from the elliptical transfer orbit delivered by Ariane 4 to the geostationary orbit by the mean of three apogee firings, thus utilizing several intermediate orbits.

. Spin stabilization :

During the transfer orbits, a 13 rpm spin rate is maintained, providing the satellite a passive stability particularly during the apogee firings. Attitude maneuvers give the spin axis an optimal direction before each firing.

. Three-axis stabilization :

After the third apogee firing, the satellite attitude is established in its normal three-axis configuration with the communication antennas directed towards earth.

For these two satellites, MMS has chosen CNES, the French National Space Agency, as the subcontractor to be responsible for LEOP activities including mainly :

- 2 GHz CNES/NASA ground stations network availability,
- flight dynamics center,
- operations control.

An integrated team, including CNES, MMS and HISPASAT personnel, was built up for the LEOP. At the FDC level, the four persons team is composed of two engineers from CNES and two from MMS.

A unique element of this mission is that all the HISPASAT LEOP operations are performed in Spain, using HISPASAT Satellite Control Center. The CNES Satellite Control Center is not employed; the Flight Dynamics Center was duplicated and MMS created a new main control room and a new satellite specialists room.

The Network Operation Center (NOC) remained in Toulouse and three specialized lines were installed between Toulouse and Madrid :

- two data lines in hot redundancy for transmission of :
  - telemetry from the NOC to the SCC and FDC,
  - localization measurements from the NOC to the FDC,
  - telecommand from the SCC to the NOC,
- one voice line which can be used for data transmission in case of double failure of the data lines.

The FDC mission preparation included the following phases :

- hardware and software installation in Madrid,
- integration with the other entities : ground stations, satellite control center, etc.,
- technical and operational qualification : simulation of nominal and degraded cases.

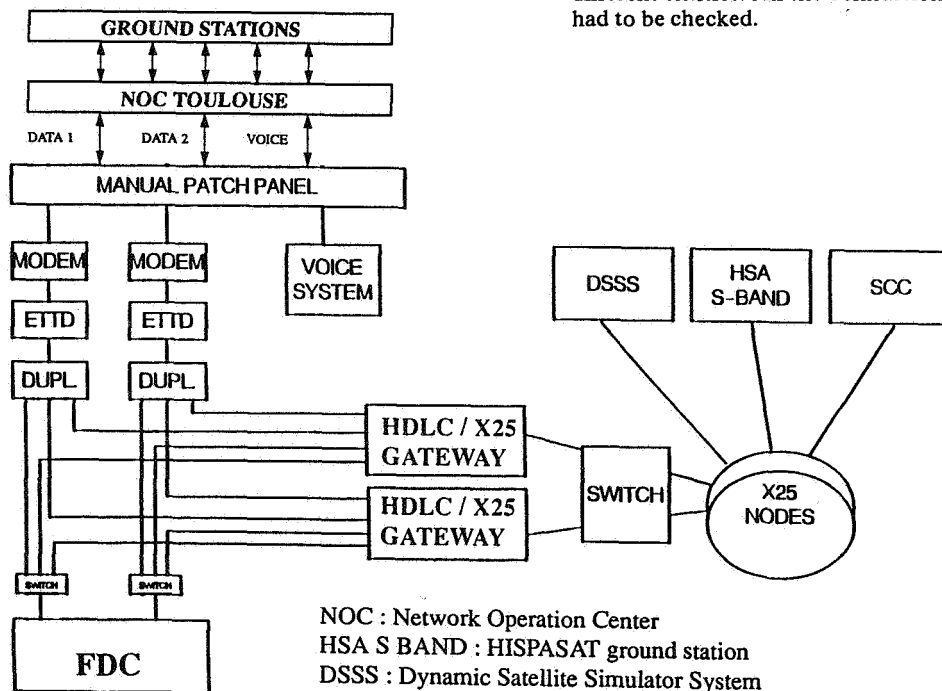


Fig. 4

## 2.2 Hardware and Software Installation

A reference hardware and software configuration in Toulouse that had been used for the Télécom 2 A and B satellites, which are very similar to HISPASAT 1A and 1B, was entirely duplicated at the Ground Control Center in Madrid.

Following specifications from FDC, MMS supplied and installed hardware and system software. Before the application software installation, FDC checked the following points :

- power supply,
- cabling,
- data transmission through the Ethernet network,
- video displays,
- laser printers,
- disks memory sharing,
- SUN operating system implementation,
- Transcript software implementation,
- HDLC software implementation,
- spare material,
- existing documentation,
- hardware maintenance organization.

Once this was completed, FDC installed the MERCATOR environment software and the flight dynamics software. To validate this essential part of the system, several test cases were defined for each flight dynamics module. They were run on the reference FDC in Toulouse and on the new FDC in Madrid. In every case, the same results had to be obtained.

## 2.3 Integration with the Other Entities

Once the installation of all the entities was completed, the technical validation of the global system began. It mainly concerned the data transmission between the different entities. All the connections described in Fig. 4 had to be checked.

Two data transmission protocols are used. The CNES LEOP system (NOC, FDC) uses the HDLC protocol, the HISPASAT Ground Control Center uses the X25 protocol. The two systems are linked by two gateways (for redundancy purposes) which enable data transmission in both directions.

For the FDC, three types of end-to-end lines had to be tested, corresponding to three different phases of the mission :

- line from the satellite simulator (DSSS) to the FDC through the gateway, for the operational qualification (see paragraph 2.4) when nominal and degraded configurations of the LEOP are simulated thanks to the telemetry provided by the satellite simulator,

- lines from the ground stations around the world to the Network Operation Center in Toulouse and from there to the FDC in Madrid through the two data flow lines. These lines allow the FDC to receive the satellite telemetry and the localization measurements during the main part of the LEOP,

- line directly from the HISPASAT S-band antenna in Madrid to the FDC through the gateway. This line is used at the end of the LEOP to receive the satellite telemetry when the satellite gets close to its station point.

#### 2.4 Technical and Operational Qualification

This is one of the most important phases of the preparation of the LEOP mission. Its purpose is the training of the different teams to face nominal and degraded configurations that may happen during typical phases of the mission, i. e. spin axis reorientation, apogee engine firing, transition from spin stabilization to 3-axis stabilization, etc. The satellite behavior is duplicated by the satellite simulator which generates a telemetry flow. The degraded cases can be due as much from a satellite failure as to a ground system hardware failure. Beyond the training of the teams, these tests check the ability of the global system to find solutions and allow the responsibilities of each entity to be precisely organized.

#### 2.5 Mission Preparation Effort

Globally for the FDC, the LEOP preparation lasted 18 months. Most of the time was spent in Toulouse, France, for :

- mission analysis,
- improvement of the flight dynamics software,
- preparation of the missions in Spain.

The missions in Spain lasted around 2 months which main part concerned the technical and operational qualification.

As the two FDC MMS engineers, since they had never participated to a LEOP mission before, these 18 months enabled them to learn the flight dynamics aspects from a theoretical and operational point of view.

### 3. RESULTS OF THE LEOP MISSION OF HISPASAT 1-A

#### 3.1 Space Mechanics Results

HISPASAT 1-A was launched by an Ariane 44LP on the 10th of September in the evening at the opening of the launch window. The initial transfer orbit delivered by the launcher was very close to the nominal targeted orbit. The nominal strategy was successful, that is to say the three apogee engine firings happened as foreseen at the 4th, 8th and 11th apogees.

##### 3.1.1 Attitude Determination

The objective of the attitude determination is to know the orientation of the spin axis in order to perform a slew maneuver to get the optimal apogee firing attitude.

For this, the FDC uses the data provided by the satellite Earth Sun Sensor (ESS) composed of two solar slits detecting the sun and two infra-red sensors detecting the earth. The required accuracy on attitude determination was 2 deg.

On the table below, one can see the accuracy obtained by comparing the determined attitude before the apogee maneuvers to the results of the calibration of the apogee maneuvers with the orbits before and after the firings.

	Apogee firing 1	Apogee firing 2	Apogee firing 3
Error on attitude (deg)	0.17	0.29	0.17

##### 3.1.2 Orbit Determination

The high quality of localization measurements enabled FDC to consistently provide adjusted orbital parameters on time. During apogee firings 1 and 3, the satellite was within visibility of three stations which were configured to provide composite Doppler measurements enabling the FDC to perform real-time determination of the orbit during the maneuvers. The accuracy of the determined orbit at the end of the firings was better than 5 km on the semi-major axis.

##### 3.1.3 Cost of the LEOP

Given the initial orbit provided by Ariane, the minimum cost (without any dispersion on the attitude determination, the orbit determination or the performances of the apogee engine) would have been 1 507.27 m/s. The speed increments really performed were the following ones :

- apogee firing 1 : 722.57 m/s,
- apogee firing 2 : 680.49 m/s,
- apogee firing 3 : 101.41 m/s,
- station acquisition maneuvers : 3.15 m/s.

The station acquisition maneuvers are the minor speed increments performed with the satellite thrusters after the third apogee firing to complete the station acquisition at 30° W longitude.

The total cost of the LEOP was then 1 507.62 m/s, which can be considered very good.

### 3.2 Operational Results

During HISPASAT 1-A LEOP, a team of only four people including two beginners operated MERCATOR successfully. From an operational point of view, the main performances of the system were :

. hardware security :

- the data acquisition was performed in hot redundancy on two workstations,
- three workstations were sufficient to perform the operations, with the fourth one used for hot redundancy,
- every monitoring display had a back-up during critical phases,
- there was a large margin for processing load (30 %) ;

. flexibility :

- each member of the team was able to perform any task and had, at any given time, a complete representation of the current positioning situation ;

. operational security :

- MERCATOR allowed flight dynamics experts to use various analysis tools and to perform cross checking of their results ;

. simplicity :

- each computation program uses standard interfaces and can be initialized easily due to powerful man machine interface,
- flight dynamics experts rapidly performed numerous runs in different modes to produce results with the best possible accuracy.

## CONCLUSION

The LEOP mission of HISPASAT 1-A was very successful.

From the space mechanics point of view, this was due to a good initial orbit, the good behavior of the satellite, the quality of the attitude and orbit measurements, the accuracy of the attitude and orbit determinations, the good optimizations and calibrations of the apogee maneuvers and the reliability of MERCATOR software.

From the operational point of view, the MMS, CNES and HISPASAT integrated team functioned very well. Thanks to its flexibility, the integration of the FDC with the other entities was rapidly completed.

For upcoming missions abroad, the HISPASAT mission demonstrated the ease of moving the FDC and linking it to another satellite control center. This enables the customer to test its satellite control center during the preparation of the LEOP instead of waiting for the beginning of the station keeping.

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